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Introduction

In the modern knowledge economy, societies are demanding greater mathematical and scientific literacy and expertise from their citizens than ever before. At the heart of such demands is the need for greater engagement by students with school mathematics and science. As the OECD/PISA definition of numeracy puts it:

> "Mathematical literacy is an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgements and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen"(OECD, 2003)

Values are an inherent part of the educational process at all levels, from the systemic, institutional macro-level, through the meso-level of curriculum development and management, to the micro-level of classroom interactions (Le Métais, 1997) where they play a major role in establishing a sense of personal and social identity for the student. However the notion of studying values in mathematics education is a relatively recent phenomenon (Bishop, 1999). According to Chin, Leu, and Lin (2001), the values portrayed by teachers in mathematics classrooms are linked to their pedagogical identities. Seah and Bishop (2001) describe the values held by teachers as representing their 'cognisation' of affective variables such as beliefs and attitudes, and the subsequent internalisation of these values into their respective affective-cognitive personal system.

Even in science education the study of values in classrooms is not a major focus of research. Nevertheless, in mathematics and science education values are crucial components of classrooms' affective environments, and thus have a crucial influence on the ways students choose to engage (or not engage) with mathematics and science. Clearly the extent and direction of this influence will depend on the teachers' awareness of, respectively, values ascribed to the particular discipline, the values carried by their selection from the available pedagogical repertoire, and their consciousness or otherwise of imposing their own personal values (Pritchard & Buckland, 1986).

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Data from a previous research project, Values and Mathematics Project (VAMP) has shown that teachers of mathematics are rarely aware of the values associated with teaching mathematics (FitzSimons, Seah, Bishop & Clarkson, 2000). Furthermore, any values 'teaching' which does occur during mathematics classes happens implicitly rather than explicitly (Bishop, 2002).
(Various relevant papers from that study, and from other authors, are available from this website: http://www.education.monash.edu.au/centres/scienceMTE/vamppublications.html)

This paper will report on ideas developed from a more recent research project concerned with values in both mathematics and science education.

Theoretical framework

Comparing values teaching in different subject areas is a relatively novel research approach and some parallel research on teachers of mathematics and history by Bills and Husbands (2004), which builds on the ideas of Gudminsdottir (1991) from English and history teachers, also shows what can be learnt from this approach.

It was decided that for this study, in order to have some basis for the mathematics and science comparisons it would be necessary to use an established theoretical framework for the values studied. We used the six values cluster model developed by the author (Bishop, 1988), based on his analysis of the writings concerning the activities of mathematicians throughout Western history and culture. It is important to stress that the emphasis in that analysis was not primarily on which values might be, are, or should be, emphasised in mathematics education, but rather on the development of mathematics as a subject throughout Western history.

In this model, six value clusters are structured as three complementary pairs, related to the three dimensions of ideological values, sentimental values, and sociological values. These three dimensions are based on the original work of White (1959), a renowned culturologist, who proposed four components to explain cultural growth. White nominated these as technological, ideological, sentimental (or attitudinal), and sociological, with the first being the driver of the others. Bishop (1988) argued that mathematics could be considered as a symbolic technology, representing White's technological component of culture, with the other three being considered as the values dimensions driven by, and also in their turn driving, that technology. The six sets of value clusters are structured as shown in *Figure 1*.

1. Epistemology of the Knowledge (Ideological values)

1a Rationalism

Reason Explanations Hypothetical Reasoning Abstractions Logical thinking Theories

1b Objectivism

Atomism Objectivising Materialism Concretising Determinism Symbolising Analogical thinking

2. How individuals relate to the knowledge (Sentimental or attitudinal values)

2a Control

Prediction Mastery over environment Knowing Rules Security Power

2b Progress

Growth Questioning Alternativism Cumulative development of knowledge Generalisation

3. Knowledge and Society (Sociological values)

3a Openness

Facts Universality Articulation Individual liberty Demonstration Sharing Verification

3b *Mystery*

Abstractness Wonder Unclear origins Mystique Dehumanised knowledge

Figure 1. Values of Western Mathematical Knowledge (Bishop, 1988)

The six value clusters that Bishop (1988) originally identified are described as follows:

> The particular societal developments which have given rise to Mathematics have also ensured that it is a product of various values: values which have been recognised to be of significance in those societies. Mathematics, as a cultural phenomenon, only makes sense if those values are also made explicit. I have described them as complementary pairs, where *rationalism* and *objectism* are the twin ideologies of Mathematics, those of *control* and *progress* are the attitudinal values which drive Mathematical development, and, sociologically, the values of *openness* and *mystery* are those related to potential ownershiop of, or distance from Mathematical knowledge and the relationship between the people who generate that knowledge and others. (Bishop, 1988, p.82)

Values in Mathematics and Science

Regarding their similarities, both mathematics and science are taken as ways of understanding that are embedded in rational logic - focusing on universal knowledge statements. Both are seen by society in general as essential components of schooling, rivalled only by literacy. Hence, teachers of each face substantial political and social pressures from outside the school (e.g., system-wide assessments of student performance, purposes for teaching seen as being directly related to technological development, etc.). In their teaching, both involve following routines, although not exclusively. Both involve modelling, albeit with different emphases. Similarly each is incorporated into the other's applications but in an asymmetrical relationship.

On the other hand, science curricula/texts commonly contain a section on "The Nature of Science" while mathematics rarely contains the equivalent. While the values embedded in mathematics teaching are almost always implicit, in science teaching some are quite explicit. For example, curriculum movements such as *Science-Technology-Society* make some values explicit and central to the intended learning outcomes; laboratory work seeks to make explicit such values as 'open mindedness,' 'objectivity,' etc.; and content described as *The Nature of Science*, for example, also makes some values explicit (see also UNESCO, 1991).

Among the general public, although the concept of 'a science industry' or 'scientific industries' is widely recognised, this is not the case for mathematics. In the popular media (e.g., magazines, newspapers, books, radio, television), science receives much more attention than mathematics, despite there having been a few recent movies featuring mathematical prodigies. Even when it is present, mathematics is generally subsumed under science. In the case of the popular pursuit of gambling, where mathematical thinking might be considered to play an important role, this is generally not the case as 'luck' seems to be considered a critical factor for many people.

Yet mathematics plays a much more prominent role as a gatekeeper in society than does science. For example, it is often used as a selection device for entry to higher education or employment, even when the skills being tested are unrelated to the ultimate purpose. In broad terms (e.g. modelling or simulations which reduce costs and/or danger), mathematics is considered to be publicly important; at the very same time as it is considered to be personally irrelevant (Niss, 1994), apart from the obvious examples of cooking, shopping and home maintenance. Politically, mathematics has been ascribed a *formatting role* in society (Skovsmose, 1994).

Differences in values between Mathematics and Science, as perceived by the educators in the project.

The project involved two mathematics educators and two science educators, and in the first part of the project there was considerable discussion and analysis of this initial framework, particularly in relation to whether the same structure could hold for science (see Corrigan, Gunstone, Bishop & Clarke, 2004). As a result of this analysis, a comparison of values between the mathematics and science educators was achieved, as shown in *Figure 2*.

Mathematics	Science
Rationalism Reason Explanations Hypothetical reasoning Abstractions Logical thinking Theories	***Rationalism*** Reason Explanations Hypothetical reasoning Abstractions Logical thinking Theories
Empiricism Atomism Objectivising Materialism Concretising Determinism Symbolising Analogical thinking	**Empiricism** Atomism Objective Materialisation Symbolising Analogical thinking Precise Measurable Accuracy Coherence Fruitfulness Parsimony Identifying problems
Control Prediction Mastery over environment Knowing Rules Security Power	**Control** Prediction Mastery over problems Knowing Rules Paradigms Circumstance of activity
Progress Growth Questioning Cumulative Development of knowledge Generalisation Alternativism	***Progress*** Growth Cumulative development of knowledge Generalisation Deepened understanding Plausible alternatives
Openness Facts Universality Articulation Individual liberty Demonstration Sharing Verification	***Openness*** Articulation Sharing Credibility Individual liberty Human construction
Mystery Abstractness Wonder Unclear origins Mystique Dehumanised knowledge Intuition	**Mystery** Intuition Guesses Daydreams Curiosity Fascination

Figure 2: Comparison between values associated with mathematics and science.

As can be seen there is a considerable amount of agreement, but there are some important differences. As far as the Ideological dimension is concerned there are both similarities and differences. In the cluster of Rationalism there is much agreement, as both subjects require the use of all the logic skills available and thus emphasise the range of values associated with those skills. With the value cluster of Objectism, which became recast as ‘Empiricism’ in order to accommodate the scientists’ approach, there is also some agreement, but the highly empirical nature of science means that it has many more value aspects there than does mathematics. The experimental and observational activities of science bring other values into play than we can find in doing mathematics.

For the Sociological dimension, with the complementary pairing of Control and Progress, there was once again some agreement between the mathematics and science educators about the Control value cluster, with its emphasis on prediction, mastery, and procedural rules. However the circumstances of the activity and different paradigms are significant in science but have little meaning in mathematics. Likewise with Progress, the idea of the cumulative development of knowledge is clearly similar, but the role of science in continuing to deepen understanding of a phenomenon again has no parallel in mathematics development.

Some other differences appear with the Sentimental dimension, that is the way individuals relate to the knowledge of the subject. In relation to the Openness value cluster, the emphasis of science on credibility and human construction are significant, compared with the idea of 'facts' in mathematics and the value of verification, sometimes via proof. With Mystery, which itself is a rather mysterious category, the dehumanised nature of mathematics with its abstractness and unclear notions of the origins of ideas contrasts strongly with the intuition, daydreaming, and empirically-based guesses of the scientists.

When considering these contrasts it is important to remember that this framework involves pairs of clustered values along the three dimensions. So the two clusters should not be considered as dichotomous, but rather as complements of each other. For example, Openness is the complement of Mystery, and therefore both clusters are present to some extent in that value dimension. Furthermore, what the model suggests is not that science and mathematics are markedly different but that there are strong similarities in their values, as befits their common heritage. There are however some interesting and, in terms of education, revealing different values represented also.

Mathematics and science teachers' values and practices

We now turn to some of the data collected from the primary and secondary teachers by means of specially constructed questionnaires. They were based on the three complementary pairs, Rationalism and Empiricism, Control and Progress, Openness and Mystery, discussed above. The same structure was used for the mathematics and the science questionnaires and for the primary and secondary teachers, although there were some minor adjustments in the descriptions of teaching situations. 13 primary teachers of years 5/6 and 17 secondary teachers of years 7/8 volunteered to answer these questionnaires. Primary teachers in the state system in Australia teach both subjects to their classes, and we also chose secondary teachers who taught both subjects to the same classes.
Questions 1 and 2 of the questionnaires ask for the extent to which particular activities are emphasised in practice in the teacher's mathematics (and science) classes. The items in these questions are designed to explore, in sequence, aspects of Rationalism and Empiricism, Control and Progress, Openness and Mystery. So, the first three statements in Qu.1 all relate to the value of Rationalism, and so on through the 18 items in Question 1.

Question 2 uses the same structure (a group of 3 items relating to each of the 6 values in the three pairs) to ask about the frequency of use of specific classroom activities. For all the statements in Questions 1 and 2, we scored the responses as 4 (for "Always"), 3 ("Often"), 2 ("Sometimes"), 1 ("Rarely"), and also calculated means. We recognise that in doing this we have taken an ordinal scale and treated it as if it was a ratio scale.

To facilitate comprehension of the results, we have combined the data for Questions 1 and 2, and in the data reported below, for example, a teacher's view of the frequency of emphasis on Rationalism in his/her class' activities is represented by the mean score for the six items relating to that value cluster in the two questions.

Questions 3 and 4 are the questions which concern the teachers' preferences for the six value clusters described above. The structure of these questions is that each question contains 6 statements to be ranked by the teachers. Each statement relates to one of the values clusters, for example, the statement "It develops creativity, basing alternative and new ideas on established ones" relates to the value of Progress. The other statements follow closely the other value descriptors although their order is different in the two questions. Note also that although the teachers knew we were studying values, they were not made aware of the value structure underlying the questions and the various statements.

Tables 1-4 show the results from the two groups of teachers in terms of their rankings of the six values clusters. In brackets are the means of (a) the frequencies in Questions 1 and 2, and (b) the rank orders in Questions 3 and 4.

Table 1 Teachers' preferred values and their preferred teaching practices: rank orders: Primary Mathematics

	Rationalism	Empiricism	Control	Progress	Openness	Mystery
Qus. 1/2	4 (2.64)	2 (2.80)	1 (2.95)	5 (2.44)	3 (2.65)	6 (2.25)
Qu. 3	2 (2.30)	1 (1.46)	6 (5.23)	4 (3.15)	3 (3.53)	5 (3.61)
Qu. 4	3 (3.66)	1 (1.33)	5 (3.75)	2 (3.00)	3 (3.66)	6 (3.83)

We can see that from Table 1 that there is a close similarity between the primary teachers' views on questions 3 and 4, and some close correlation between them and questions 1/2 particularly regarding Empiricism, Openness and Mystery. However, the ranks for Control stand out as being markedly different.

Table 2 Teachers' preferred values and their preferred teaching practices: rank orders: Primary Science

	Rationalism	Empiricism	Control	Progress	Openness	Mystery
Qus. 1/2	2 (3.05)	3 (2.90)	1 (3.07)	4 (2.57)	5 (2.47)	6 (1.91)
Qu. 3	2 (2.75)	1 (1.41)	6 (4.91)	4 (3.41)	5 (3.66)	3 (3.00)
Qu. 4	4 (3.41)	1 (1.41)	6 (4.75)	3 (3.33)	5 (3.83)	2 (2.58)

For Science the primary teachers again express similar views for Questions 3 and 4, and once again the ranks for Control are markedly different from that in Questions 1/2. Mystery is also ranked differently in practice from the teachers' preferred views.

Table 3 Teachers' preferred values and their preferred teaching practices: rank orders: Secondary Mathematics

	Rationalism	Empiricism	Control	Progress	Openness	Mystery
Qus. 1/2	2 (2.15)	3 (2.05)	1 (2.75)	5 (1.93)	4 (1.99)	6 (1.79)
Qu. 3	1 (1.94)	2 (2.05)	6 (4.52)	4 (3.88)	3 (3.35)	5 (4.29)
Qu. 4	1 (1.70)	2 (1.82)	3 (3.44)	4 (4.00)	4 (4.00)	6 (4.47)

The secondary teachers rank Rationalism highest for mathematics in terms of their preferred values (Questions 3 and 4) but, like their Primary colleagues, they place Control in the highest rank in practice.

Table 4 Teachers' preferred values and their preferred teaching practices: rank orders: Secondary Science

	Rationalism	Empiricism	Control	Progress	Openness	Mystery
Qus.1/2	1 (2.86)	3 (2.61)	2 (2.84)	5 (2.30)	4 (2.33)	6 (2.03)
Qu. 3	4 (3.18)	1 (1.25)	6 (5.87)	4 (3.18)	3 (3.06)	2 (2.81)
Qu. 4	3 (3.12)	1 (1.25)	6 (4.12)	2 (3.00)	5 (4.06)	4 (3.33)

For the secondary teachers and science, Questions 3 and 4 show us that the teachers' main value preference is for Empiricism, but in practice they favour Rationalism with Control coming a close second. Once again we can see differences with respect to Control, but this time also with Mystery.

The comparisons between the values in mathematics and science for the two groups of teachers show interesting differences, reflecting their concerns with the curriculum and teaching at their respective levels. For the primary teachers, concerning Ideology, they prefer Empiricism over Rationalism for both science and mathematics, though both are important, rankings which are also reflected in the findings for their preferred practices. At the primary level of course much mathematical work is empirical in nature. For the Sentimental dimension, Control is much less favoured than Progress also for both, but the practices are very different. Another main difference between the subjects appears in the Sociological dimension where Openness and Mystery reverse their positions with the two subjects, the first being more favoured than the second in mathematics and the reverse in science. This difference does not translate to the practices however, with the science practices being ranked much more like the mathematics practices.

For the secondary teachers, concerning the Ideological dimension, they favour Rationalism for mathematics and Empiricism for science, disagreeing with the primary teachers. For the Sentimental dimension, the secondary teachers largely agree with their primary colleagues and for the Sociological dimension, they again agree with their primary colleagues favouring Openness for mathematics compared with Mystery, and reversing these for science. Indeed Mystery for science is ranked 2 and 4 by the secondary teachers and ranked 2 and 3 by the primary teachers, showing how significant they consider that aspect to be.

Conclusions and implications

The comparison of the values between the science and mathematics educators in the project has revealed perceptions of some important differences between the two subjects. It has also helped to clarify the values structure underlying the current project. In particular, regarding the Ideological dimension, there was evidence that mathematics educators favour the cluster of Rationalism while science educators emphasises Empiricism.

With the Sociological dimension, while both subjects favour Control, the values of Progress differ, with science seeking to deepen understanding of relationships rather than constructing new knowledge as in mathematics. Concerning the Sentimental dimension, there are important differences in both the Openness and Mystery clusters with science seeming to relate more to the humanising aspects of knowledge compared with mathematics.

The comparisons between the values in mathematics and science for the teachers also show interesting differences, reflecting their concerns with the curriculum and teaching at their respective levels. At the primary level the teachers favour Empiricism over Rationalism for both science and mathematics, though both are important, and this contrasts with the findings above. At the primary level of course much mathematical work is empirical in nature. For the Sociological dimension, Control is much less favoured than Progress also for both. The main difference between the subjects appears in the Sentimental dimension where Openness and Mystery reverse their positions with the two subjects, the first being more favoured than the second in mathematics and the reverse in science. This difference shown by the primary teachers reflects the educational implications of the educators' views above.

For the secondary teachers, the Ideological dimension reflects the educators' views, with mathematics favouring Rationalism and science favouring Empiricism, disagreeing with the primary teachers. For the Sociological dimension, the secondary teachers largely agree with their primary colleagues and for the Sentimental dimension, they again agree with their primary colleagues favouring Openness for mathematics compared with Mystery, and reversing these for science. Indeed mystery for science is ranked 2 and 4 by the secondary teachers and ranked 2 and 3 by the primary teachers, showing how significant they consider that aspect to be.

In general, the conceptualisation put forward for this project has begun to show interesting and interpretable results. Discussions with the teachers have revealed an interest in the issues of values teaching in all subjects, but also a lack of vocabulary, and conceptual tools to enable them to develop explicitly the values underlying mathematics education. One of the goals of this project was by contrasting mathematics and science, to help teachers develop those conceptual tools further. As we have seen, and as has been shown above, the contrasts between these two closely related forms of knowledge are provocative, and already reveal worthwhile challenges particularly for mathematics teaching to pursue.

For example, the difference between the emphasis on Empiricism at primary level and on Rationalism at secondary level implies some important challenges for explicit values development in the teaching of mathematics at those two levels. How should that values development be smoothed across the primary/secondary divide?

The differences in the views on Progress are also revealing, with the development of understanding in science contrasting with the construction of new knowledge in mathematics. How can we reconstruct our views of the mathematics curriculum so that progress through that curriculum is not just a matter of acquiring new knowledge but of ensuring that it also deepens learners' understanding of what has been taught before?

Finally could the dehumanised, highly abstract and mystique-laden value of Mystery of mathematics which appears to be such an obstacle to mathematics learners be made more explicit so that it could be challenged by the more humanised and personal intuitive nature of that value which science appears to enjoy?

However, before jumping to too many conclusions, we must remember that the data are from questionnaires and consist of teachers' reported views of their preferences and their practices. We do not know the extent to which their rankings of these practice statements reflect their actual practices. However, the data for science at the secondary level, where teachers emphasises other values than mathematics, indicates the usefulness of comparing subjects and their values emphases.

Finally one can see that, if the data reported here are valid, the differences show that teachers' values in the classroom are shaped to some extent by the values embedded in each subject, as perceived by them. This implies that changing teachers' perceptions and understandings of the subject being taught may well change the values they can emphasise in class. Further if teachers wish to emphasise values other than those they currently emphasise, it is possible to learn strategies from their teaching of other subjects.

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